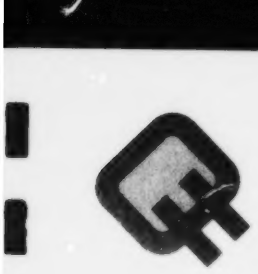

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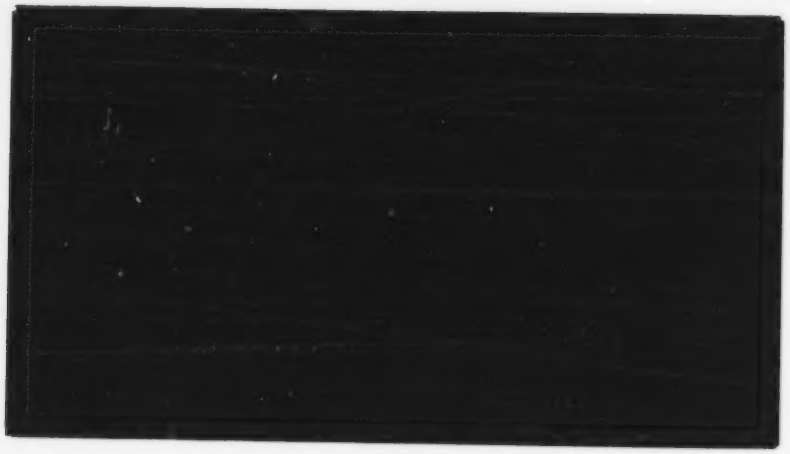

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FUTURE OXYGEN REQUIREMENTS OF THE METALLURGICAL INDUSTRY IN ONTARIO

Report No 90-156-K

R.A. Reesor, R.A. Bergman, F.J. Pearce
Metallurgical Research Department

ABSTRACT

Ontario Hydro Research Division was contracted by Technical Services and Development Department to carry out an assessment of the future oxygen requirements of the Ontario metals producing industry. The study was carried out to assist in load planning and to identify any prospects for off-peak production of oxygen. The main potential for load reduction lies in the non-integrated steel plants where oxygen can be substituted for power input through the arc. This is assuming constant production levels of steel. The use of oxygen in the integrated steel plants and in the non-ferrous smelters is expected to increase substantially resulting in an increased power requirement. Load shifting could be applied to existing oxygen plants with excess capacity but it is not economically viable to overdesign new plants.

job	file	date	report no
80-122-111	808.-274	July 18, 1990	90-156-K

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EXECUTIVE SUMMARY

FUTURE OXYGEN REQUIREMENTS OF THE METALLURGICAL INDUSTRY IN ONTARIO

R.A. Reesor, R.A. Bergman, F.J. Pearce
Metallurgical Research Department

Ontario Hydro Research Division was contracted by Program Support and Services Division to carry out a study of the future requirements for oxygen in both the ferrous and non-ferrous industries. Two consultants were employed to review the processes involved and the changes that will take place which will require increased oxygen usage. The study was based on the literature, consultants knowledge and information gained by direct contact with the metallurgical companies and the oxygen suppliers.

It was found that there will be a large increase in oxygen usage in the steel industry. The electric furnace steel producers (Mini Mills) will increase the use of oxygen in order to decrease the melting time to produce steel. The net result will be a lowering of electrical power requirements in steelmaking because of the heat generated by burning supplementary fuels with the oxygen. The integrated steel producers will modify the blast furnace process by adding oxygen enrichment to the air going into the furnace to permit the injection of high levels of coal in order to partly replace the need for coke. One of the steel companies has recently modified their BOF operation by injecting oxygen into the freeboard to increase the post combustion efficiency to raise the amount of scrap that can be smelted.

The oxygen consumption in the non-ferrous industry will also increase. INCO has purchased a new oxygen plant as part of their program to modify their smelter to an all flash-smelting operation. Falconbridge will be using purchased liquid oxygen to increase the company's capacity to treat secondary materials. Kidd Creek is planning to increase the capacity of its copper smelter through increased productivity by the use of a higher degree of oxygen enrichment in the process air.

job	file	date	report no.
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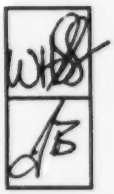
The use of oxygen in Ontario will increase from the current 5889 tonnes/day to 7389 tonnes/day and will result in an increase in energy requirements of approximately 24 MW by the year 2000. This increase will be partially offset by a decrease in power requirements per tonne of steel by the electric furnace industry. However these producers will be able to make more steel per unit of time, therefore the power savings will only offset the need for the increased power requirements for a period of time. The electric furnaces will require 22 MW less direct electrical load for melting due to the increased consumption of oxygen. The increased use of oxygen in the blast furnaces of the integrated steel companies could also lead to an additional 23.5 MW of increased electrical load. Therefore, there will be a large net increase in electrical energy consumption by this sector of the steel industry.

The additional oxygen required by the non-ferrous industry is needed to meet required increased plant capacities and to comply with SO_2 emission regulations. It is doubtful that the increase in oxygen usage in the non-ferrous industry will reduce the electrical process energy requirements in other areas substantially. Therefore, there will be a net increase in electrical energy consumption by this industry.

It is estimated that the net increase in oxygen usage in the ferrous and non-ferrous industry will result in an increase of 2 MW in electrical power. However, this is strongly dependent upon the amount of direct electrical energy replaced by increased oxygen use in the electric furnace steel industry. Also, if oxygen enrichment is employed by all Ontario blast furnaces then 23.5 MW of new oxygen capacity will be required.

The application of load shifting to a new oxygen plant does not appear to be economically viable, however, it is feasible for an existing plant with excess production capacity.

It is important to realize that the future new uses of oxygen in the primary metals industry represent a delicate balance between increased load for oxygen production and decreased load through use of oxygen in electric arc furnace steel production. The projected small net increase in load (2 MW) will only come about if all the new future uses of oxygen are realized. If the EAF operators do not develop and utilize oxygen injection into their melting furnaces the load reduction in EAF steel making will not offset oxygen related load increases at integrated steel plants.



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To: Dr. N. Burnett
Supervising Engineer
Industrial Technology & Products

FUTURE OXYGEN REQUIREMENTS OF THE METALLURGICAL INDUSTRY IN ONTARIO

1.0 INTRODUCTION

In recent years the metals industry has undergone a number of technological changes to remain competitive. One of these changes has been the increased use of high purity oxygen. In the steel sector this resulted from the need to increase productivity and/or to permit the direct use of carbon fuels in the processes. In the non-ferrous industry this was also done to increase process intensity and as a means of converting to more environmentally acceptable processing routes.

It is important to understand the direction the metals industry will take with respect to the use of oxygen. This is particularly true for those processes where reductions in electrical power requirements will result.

This report reviews the information obtained from direct consultations with Ontario industry (1) and the literature (2-7). It provides an estimate of future oxygen usage and the possible effect it will have upon Ontario's electrical load demand.

2.0 STATUS OF OXYGEN PRODUCTION TECHNOLOGIES (8)

The production of oxygen has had a very close relationship with the metallurgical industry. Oxygen has been employed to intensify processes, increase efficiency and to decrease costs over the past 40 years.

Although, the uses of oxygen in the first years, early 1900's, were essentially restricted to welding and cutting, the goal was large scale production plants to serve metallurgical industries. The development of oxygen plants to their present state has taken place very slowly. The power required per tonne of oxygen started at about 1000 kWh at the time of its first production and decreased rapidly to about 500 kWh by 1915. Progress from this point was relatively slow and it wasn't until the 1950's that it reached the 300 kWh/tonne level. The progress of energy consumption from the beginning is represented in Figure 1.

It is extremely difficult to talk about the economics of oxygen production without the details of quantity, purity, location and demand. The breakdown of cost has remained essentially the same for the last two decades. The two main components are capital and electrical energy which represent 50 and 30 percent respectively of the total production cost. Labour costs are low 5-7 percent and with computer control they are getting lower. The remaining 10-15% are items such as insurance, maintenance, taxes, etc. The energy cost, size of plant, product purity and pressure all have an influence on a plant's cost. To determine the project viability, the specific conditions must be considered, the most suitable process chosen and some trade-offs may be necessary between capital and energy cost.

The future of the oxygen industry will be very closely related to technology developments in both the metallurgical and chemical industries. Historically, the oxygen industry has played a very strong role in assisting industry in the development of technologies which increase process productivity and decrease production costs through the increased use of oxygen.

Traditionally, the majority of oxygen production came from cryogenic air separation plants. Over the past decade, the range of industrial uses and consumption patterns have expanded to include the smaller and more cyclical requirements as well as the previous large, continuous applications. There have also been an increasing number of applications for purities below the traditional industrial standard of 99.5%. This has resulted in the need for new technologies to handle this new array of applications. Adsorption technologies have been considered in lower purity applications. Membrane based systems have advantages when the tonnage is small and intermittent and if enriched air (<50% O_2) is required. Molten salt based systems are in early stages of development, and will offer reduced energy costs for larger applications. The traditional cryogenic operation is continually being made more efficient through advancements made in areas such as computer control.

The energy consumption is a large part of the cost to produce oxygen in larger plants, but the importance decreases with plant size. Recovery relates to the efficiency of a plant and controls the equipment size and hence the cost. Although adsorption and membrane technologies compete with cryogenic plants at smaller production rates, as the production rates increases and energy cost begins to control the cost of oxygen, on-site cryogenic plants become the economic choice. For high purity oxygen cryogenic production is the only technology available at present.

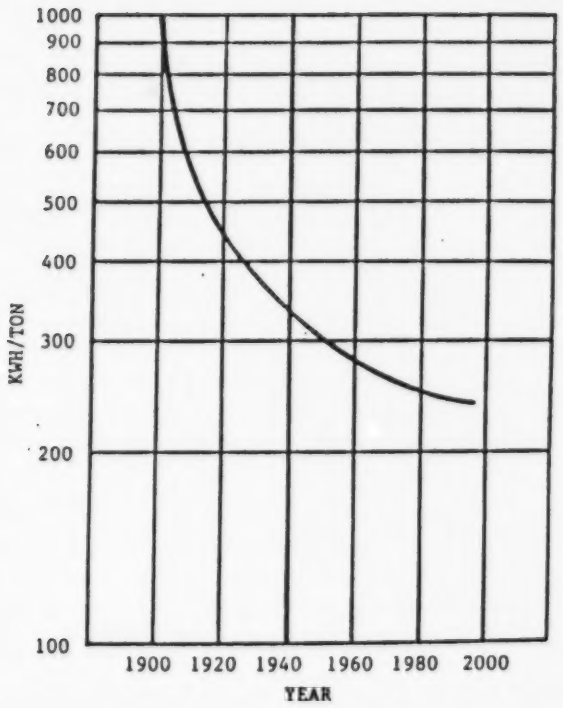

FIGURE 1: ENERGY CONSUMPTION

Eyre, D, Gorup, I.L., "Production of Oxygen - Keeping Pace with Metallurgical Demands"

Adsorption

These processes are based on the ability of some natural and synthetic materials to preferentially adsorb nitrogen or oxygen molecules. Some materials, such as aluminosilicates, adsorb nitrogen molecules more strongly than oxygen or argon. As air is passed through a bed of this material nitrogen is retained and an oxygen rich stream exits the bed.

Aluminosilicates are currently used in most adsorption based processes for oxygen production. Pressurized air enters a vessel containing the adsorbent. Nitrogen is adsorbed and an oxygen-rich effluent stream is produced until the bed is saturated. The feed air is then switched to a new vessel and regeneration of first bed begins. Regeneration is carried out either by heating the bed or reducing the pressure. Both procedures will reduce the nitrogen holding capacity of the adsorbent. Heating the bed is referred to as Temperature Swing Adsorption and pressure reduction as Pressure or Vacuum Swing Adsorption. Pressure reduction has a faster cycle time and therefore is usually the preferred choice.

Adsorption processes have a limit of 93-95% maximum oxygen purity. The cyclic nature of the process results in the bed size being the controlling factor in capital cost. Since production is directly proportional to bed volume, capital costs increase more rapidly as a function of production rate as compared to cryogenic plants. Adsorption plants appear to be feasible up to 100 tonne/day. The capital cost is quite low and compensates for the higher energy usage for adsorption processes. The start-up and shutdown are relatively easy since the systems run at almost ambient conditions. A unit can be idled overnight or over a weekend and be restarted in as little as a few minutes. The optimum application for adsorption systems are for plants smaller than 100 tonne/day at purity levels between 85 to 95% oxygen.

Membrane Technology

Partially permeable membranes have been employed for separating oxygen and nitrogen from air. The separation depends on the difference in diffusion rates of oxygen and nitrogen through the membrane which divides a high and low pressure air stream. The choice of membrane material is critical to the economics of membrane systems since the rate and purity of oxygen production are determined by the membrane material and surface area. Since oxygen molecules are smaller than nitrogen most membrane materials are more permeable to oxygen than nitrogen but most are not sufficiently selective to produce medium or high purity oxygen. Therefore, membranes are mainly used to produce enriched air (25-50% O_2). Membranes are a very simple technology which is carried out at ambient temperature. A simple blower is used to supply enough head pressure to accommodate the drop through the filters and a vacuum pump is used to maintain the pressure difference across the membrane and deliver oxygen at the required pressure. Due to the high permeability of water and carbon dioxide, they usually end up in the enriched air product.

The capital required for this technology is a direct function of the production rate. Membrane systems are however limited to applications of 20 tonnes of oxygen/day or less and where little product back-up storage is required and intermittent consumption cycles occur.

Molten Salt

A process (MOLTOX™) of liquid phase chemical air separation is being developed by Air Products and Chemicals which has a relatively low electrical energy consumption. A pilot plant has been in operation since 1986 at one-quarter scale. In the process, dry air free of carbon dioxide enters the absorber at about 500°C and 20-185 psi where it comes in contact with a molten salt. The oxygen in the air chemically reacts with the molten salt and leaves the absorber. This molten salt then flows to a desorbing vessel where it is either heated or reduced in pressure thereby liberating gaseous oxygen. After the oxygen is released, the salt is then cooled and returned to the absorber.

The primary advantage of this system is that the chemical reaction does not consume the compression energy of nitrogen, a major percentage of the air stream. Some of the energy can also be recovered. In the pressure swing absorption case, the nitrogen leaving the absorber can be expanded to recover its energy. With temperature swing adsorption, a low value waste heat source can be very important in reducing the operating cost of the process.

This process is in the very early stages of development and problems with selection of materials with suitable corrosion-resistant properties has delayed its commercial feasibility. The pilot plant did demonstrate a continuous process of absorbing oxygen from air and producing a very high purity product (99.9%). Any potential commercial plant would be best suited for a large oxygen requirement, ie 500 tonne/day or larger, where the operating efficiency offsets the larger capital requirements of the equipment.

Cryogenics

Almost all the oxygen commercially produced today is by cryogenic air separation. Cryogenic distillation is used to separate the components of air. Cryogenic systems have been used to produce oxygen in the 95 to 99.8% purity range. Either reversing heat exchangers or molecular sieve adsorption systems can be used to preheat the air for impurity removal and primary heat exchange. For purities below 95% the energy requirements are very similar therefore processes mentioned earlier are being considered to produce oxygen at purities from 70-95%

The main advantage of cryogenics is the ability to produce by-products such as nitrogen and argon and also to liquify for storage a portion of the total output. The liquid can be stored in vacuum insulated tanks for use during peak requirement periods to serve as backup for outages or for merchant sales. The turndown capability of a cryogenic plant is limited for applications with large short term variations in flow requirements. It requires a long period of time to restart and reach purity for a plant which has been shutdown. For frequent shutdowns the unproductive energy cost to restart a unit is a significant part of the operating costs.

The cryogenic process has become very efficient and improvements being considered are only in the area of computer control. The major production cost is the electrical energy for running compression equipment. The savings attainable in energy consumption yields a fast return on capital for computer equipment usually less than two years. A computer can monitor a varying product demand and quickly adjust production conditions accordingly. The rationale for a steady state optimization by a computer is to integrate heat and material balances to result in a minimum production cost. On average, computer control installation by Air Products and Chemicals has demonstrated a better than five percent reduction in energy requirements for a given production rate or a five percent increase in production capacity as compared with manual operation. Even higher savings are evident during turndowns, therefore allowing greater turndown flexibility with computer control. (Figure 2)

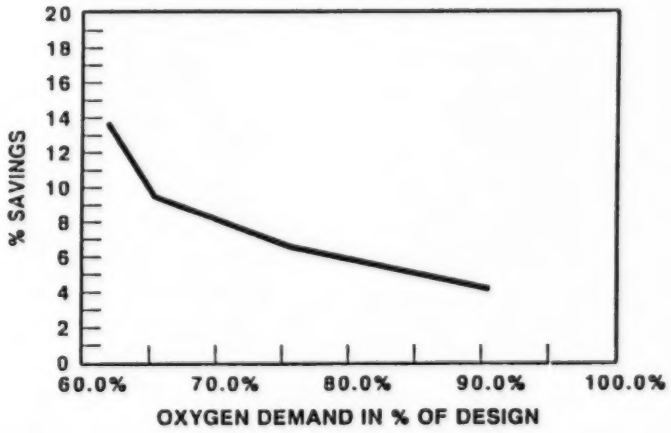

FIGURE 2: COMPUTER OPTIMIZATION SAVINGS

The objective is to minimize over-production which is vented and at the same time avoiding supplemental liquid vaporization which makes up for production deficiencies.

Cryogenic plants remain the economic choice for most medium to large oxygen requirements due to relatively low energy consumption. Liquid oxygen can also be readily produced for backup and peak shaving. A good comparative summary of all oxygen production technologies is shown in Table 1.

TABLE 1: Characteristics of Air Separation Technologies

OXYGEN PRODUCTION TECHNOLOGY					
	ADSORPTION	CHEMICAL	CRYOGENIC	LOX	MEMBRANES
STATUS	SEMI-MATURE	PILOT PLT	MATURE	MATURE	DEVELOPING
ECONOMIC RANGE	<100T/D	>500T/D	>20T/D	<50T/D	<20T/D
SPECIFIC POWER RANKING (1=LOWEST)	3	1	2	5	4
PURITY LIMIT	95%	99.9%	99.8%	99.5%+	ca.40%
STORAGE/BACKUP	ADD-ON OR HAUL IN	ADD-ON OR HAUL IN	STD	STD	ADD-ON OR HAUL IN
STARTUP TIME	MINUTES	HOURS	HOURS	MINUTES	MINUTES
FLEXIBILE PRODUCTION RANKING (1=HIGHEST)	3	5	4	1	2

3.0 SUMMARY OF ONTARIO'S CURRENT AND FUTURE OXYGEN PLANT CAPACITIES AND ENERGY REQUIREMENTS

All the major Ontario metal producers were contacted and requested to complete a short questionnaire about their present and future oxygen consumption plans. Table 2 is a summary of the existing oxygen plants and plans which were revealed about potential future plants. Also, included is a summary of the associated electrical load of each plant and potential new plants.

		OXYGEN Tonnes/day	MW
1.0	OXYGEN FOR NON-FERROUS PLANTS		
1.1	Operating		
	Inco	1225	21.0
	Kidd Creek	460	9.8
	TOTAL OPERATING	1685	30.8
1.2	Potential		
	Inco	556	7.5
	Kidd Creek	100-200	1.5-4.5
	TOTAL POTENTIAL	656-756	9.0-12.0
2.0	OXYGEN FOR STEEL PLANTS		
2.1	Operating		
	Canadian Liquid Air, Hamilton	1860	50 -60
	Dofasco, Hamilton	363	5.8
	Air Products, Nanticoke	590	12.0
	Union Carbide, St. Sault Marie	1088	24.0
	TOTAL OPERATING	3901	92.8-102.8
2.2	Potential		
	Canadian Liquid Air, 1994/95	800	13.6
3.0	MERCHANT OXYGEN PLANTS (1)		
	Union Carbide, Oakville,	163	11.0
	Liquid Carbonic	150	9.0
		313	20.0
TOTAL PRESENT		5889	143.6-153.6
TOTAL FUTURE		1456-1556	21.6-25.6

(1) Merchant Plants Produce also significant amounts of Nitrogen.

4.0 OXYGEN CONSUMPTION BY ONTARIO'S METALS PRODUCERS

Since the early 1950s the steel industry has intensified their processes by the use of high-purity oxygen. Large quantities were first used to increase the productivity of the old open hearth process. This open hearth process has been gradually replaced by the BOF (LD) process which depends entirely upon oxygen as its driving force. The electric furnace steel producers have over the same period gradually increased the use of oxygen mainly in oxy-fuel burners and by direct oxygen lancing of the scrap. The burners have sped-up the melt-down phase of the process and to some degree lowered the direct electrical energy requirements per tonne of steel produced.

The non-ferrous industry has used oxygen in large quantities since the early 1950's in several processes. The INCO and OUTOKUMPU flash furnaces use oxygen or oxygen enriched air to utilize the exothermic heat of sulphide oxidation for smelting nickel and copper concentrates. Oxygen is also used by the Mitsubishi process, as practised by Kidd Creek and by the Noranda process. Oxygen enrichment of the converter air is also practised. In general, there has been a large increase in the use of oxygen for the non-ferrous smelters during the past decades, and this trend is expected to continue.

4.1 Present Consumption of Oxygen - Steel Industry

The current consumption of oxygen in the Ontario Steel industry (2) is shown in Table 3.

TABLE 3 - CURRENT OXYGEN CONSUMPTION - ONTARIO AND CANADA

			TOTAL FOR ONTARIO	TOTAL FOR CANADA
Integrated Steel Plants	Basic Oxygen Furnace	Production 1987 (net tonnes)	9,693,126	9,843,053
		Oxygen consumed in (000 Nm^3) Steelmaking furnace	581,593	591,792
		Blast Furnace	44,679	46,079
		Other	71,004	71,004
		TOTAL	697,276	708,874
		Oxygen consumed (Nm^3 per tonne)		
		Steelmaking Furnace	54	54.5
		Other (including blast furnace)	11	11
		TOTAL	65	65.5
Non-Integrated Steel Plants	Electric Air Furnace	Production in 1987 (net tonnes)	1,592,220	4,035,940
		Oxygen consumed in (000 Nm^3)		
		Steelmaking Furnace	32,371	65,837
		Other	0	3,114
		TOTAL	32,371	68,951
		Oxygen Consumed (Nm^3 per tonne)		
		Steelmaking Furnace	18.5	15
		Other	0	0.75
		TOTAL	18.5	15.75
	Total All Furnaces	Production 1987 (net tonnes)	11,285,346	13,878,993
		Oxygen Consumed in (000 Nm^3) Steelmaking furnace	613,965	657,629
		Other (Including blast furnaces)	115,682	120,197
		TOTAL	729,647	777,826
		Oxygen Consumed (Nm^3 per tonne)		
		Steelmaking Furnaces	49	43
		Other	9	8
		TOTAL	58	51
		OXYGEN CONSUMED % BY		
		BOF	95.6%	91.1%
		EAF	4.4%	8.9%

The data in Table 3 is for the year 1987 the last year in which there was complete submissions from the industry. It is suggested that this information approximately represents the situation up to 1988. It may be seen that oxygen usage in BOF steelmaking dominates the picture. Also, up to the present time it may be seen that the consumption by the integrated companies far outweighs that of the non integrated plants.

The integrated plants use oxygen in the following processes;

. BOF and KOBM Steelmaking - Oxygen lances etc.

. Blast furnaces - Enrichment of the air blown into the furnace.

. Continuous casting - oxygen torch cut-off of slabs, blooms and other sections.

. Scarfing - Oxygen torch removal of surface defects on slabs, blooms etc.

The non-integrated plants use oxygen as follows;

. Electric arc furnace - Oxy-fuel burners and direct oxygen lancing.

. Continuous casting - oxygen torch cutting of billets

. Scarfing - Oxygen torch removal of surface defects on billets.

In order to obtain an up to date estimate of 1989 oxygen usage in Ontario, direct contact was made (1) with all steel producers. Also, a picture of current plans for increased oxygen consumption by the steel companies as they plan to modify their processes in the near future, was obtained. Table 4 summarizes these findings.

TABLE 4 - ESTIMATE OF PRESENT AND NEAR FUTURE OXYGEN CONSUMPTION AND SUPPLY CAPACITY

COMPANY	OXYGEN CONSUMPTION Tonnes/YR	
	PRESENT 1989	FUTURE
Integrated (BF/BOF)	1,062,930	1,315,380
Non Integrated (Electric Arc)	60,000	147,000
TOTAL	1,122,930	1,462,380
Oxygen Supply Capacity	1,415,700	1,706,100

It may be seen in Table 4 that the integrated companies dominate the picture in oxygen consumption.

4.2 Future Consumption of Oxygen - Steel Industry

It may be seen in Table 4 that two process areas show a marked increase in oxygen consumption, namely the blast furnace and the electric furnace.

Blast Furnace

The use of oxygen in this process has two purposes, one, to increase productivity and two, to increase the ability to inject hydrocarbons into the furnace to replace part of the coke requirements. The latter use is to make up for the coke loss as aging and environmentally unacceptable coke oven batteries are shut down. The future increase of oxygen for integrated plants as noted in Table 4 will primarily be used to allow large quantities of coal to be injected into the blast furnace at one Ontario plant, Figure 3. The old coke batteries at this point are to be closed down within the next 5 years. This coke replacement approach which has already been adopted in Europe and Japan, may spread to all of Ontario's integrated plants in the longer term.

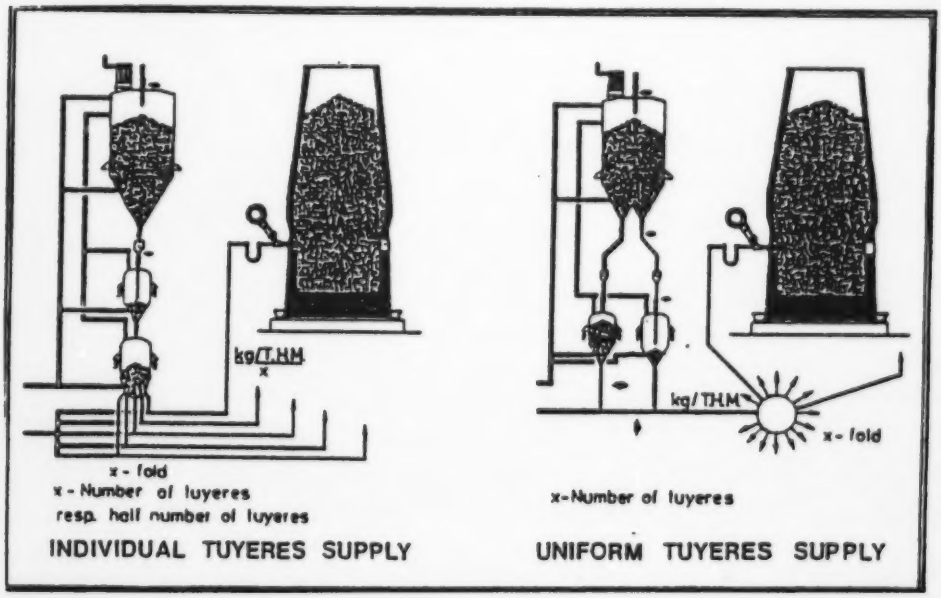

FIGURE 3 - Schematic diagram - Coal Injection into a Blast Furnace

Within the decade, assuming that the rest of Ontario's integrated industry will go the same route, as some coke ovens are gradually closed down and replaced with oxygen and coal injection the associated oxygen requirement will be enormous. Assuming that 2500 scf of oxygen will be required per tonne of hot metal (4.5% of the wind rate) and the remaining iron production in Ontario is 21120 tonnes. Then if all Ontario blast furnaces adopted this oxygen-coal injection, the additional oxygen required would be 1280 tonne/day which would result in about 23.5 MW of added load.

Electric Arc Furnace

The use of oxygen in the electric arc furnace, as shown in Table 4, will be sharply increased through the use of oxy-fuel burners and direct lancing of the scrap during melt down and lancing of the carbonized melt. This change will result in a further lowering of the direct electrical requirements of the process. It has been estimated(3) that the power requirements are decreased by 44 kW hr/tonne for every 10 NM^3 of oxygen/tonne of steel. The estimates (3) vary from 30 - 50 kW hr/tonne depending upon a number of factors on how the oxygen is employed. Figure 4 summarizes the effect that oxygen has had on productivity and electrical energy consumption over the past 10 years.

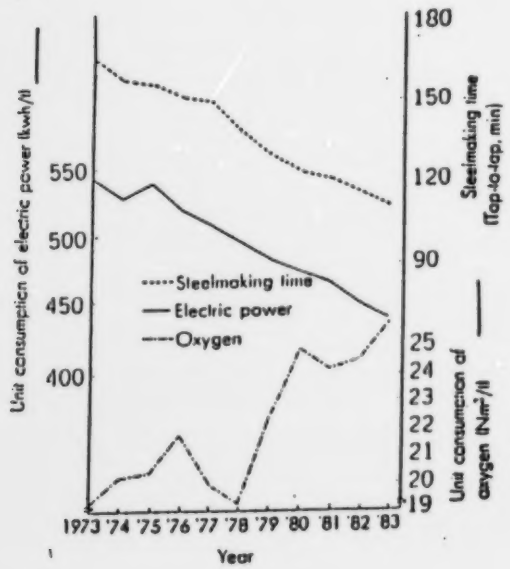

FIGURE 4 - THE EFFECTS OF OXYGEN USAGE ON ELECTRIC ARC FURNACE PERFORMANCE (3)

The Ontario companies will continue to test higher and higher levels of oxygen usage in the arc furnace with various methods of introducing carbon. The electrical energy savings may vary somewhat from the foregoing estimates. The efficiency of oxygen usage may be improved with careful additions of carbon so that acceptable yields of iron are maintained in the process.

It can be shown that the electrical energy in electric furnace scrap melting can be reduced by replacing "arc" energy by energy introduced through oxygen injection. It has been reported (3) that injection of 10 Nm^3 of oxygen can replace 40 kWh/tonne of electrical energy. An efficient oxygen plant requires 400 kWh to produce one tonne of oxygen. At present, Ontario electric furnaces are using 18.5 Nm^3 of oxygen/tonne of steel (Table 3) on average. It has been estimated from discussions with industry that over the next 5-10 years the oxygen consumption will be increased to about 34 Nm^3/tonne of steel in the electric furnace. This increase of 15.5 Nm^3 of oxygen will require 8.25 kWh/tonne of steel. The reduced direct electrical energy input from the 15.5 Nm^3 increase in oxygen usage per tonne of steel is approximately 62 kWh/tonne of steel. Therefore the net electrical energy savings achieved by increasing the oxygen consumption by 15.5 Nm^3 corresponds to 53.75 kWh/tonne of steel. Ontario's electric furnace industry has indicated that their production rate will increase to about 2.6 x 10^6 tonnes/year. On this basis the overall reduction in direct electrical power requirements will be about 22 MW. The net electrical power savings taking into account the power required to produce the oxygen will be about 19 MW. This potential saving will be pursued by the steel producers. While this is potentially a cost saving for the steel producers it is also an energy conservation possibility for Ontario Hydro. However, steel plant operators, while saving energy per tonne of steel, will probably not reduce their direct electrical power intake on a unit time basis, they will simply make more steel per unit of time over the longer term for the same amount of power. In essence, the use of oxygen increases their productivity.

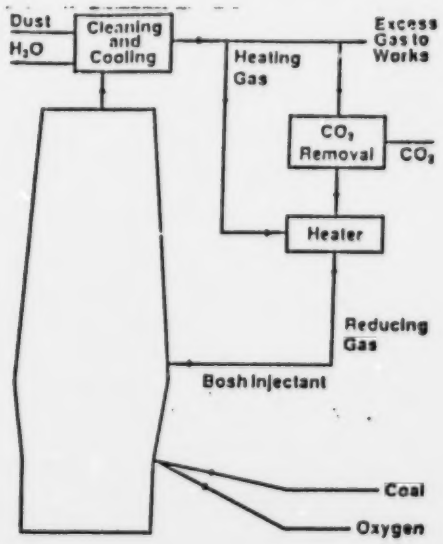

FIGURE 5 - N_2 - Free Blast Furnace with Bosh Injection

Future Potential-Integrated Companies

In the longer term, the integrated companies will likely use increased amounts of oxygen in the blast furnace and the BOF process. The extremes of these processes are already under development around the world (4). A blast furnace in Russia has been operated with 100% oxygen instead of normal hot air. Several other variations of the blast furnace with coal injection and 100% oxygen are being considered. One such variation is shown in Figure 5.

The net result here is the increased use of electricity for the production of oxygen. Many companies around the world are also attempting to replace the blast furnace with new oxygen based reduction smelting processes.

Many variations of the BOF process based on oxygen and added coal are being tested in Japan and Germany. One extreme is the KMS (6) process which is basically a BOF vessel employing oxygen and coal and much smaller quantities of blast furnace iron than the standard BOF processes. This process is essentially an extension of the KOBM process already adopted in Canada. A schematic diagram of the KMS and the KOBM processes are shown in Figure 6.

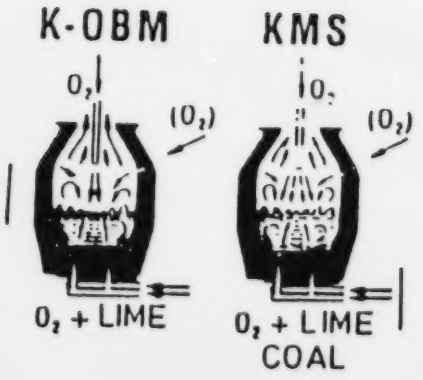

Figure 6 - K-OBM and KMS Processes

Future Potential-Non-Integrated Companies

In the longer term, the use of oxygen and supplementary fuels in the electric arc furnace context may have also been taken to the extreme. The KES (7) process, for example, employs large quantities of oxygen and coal injected into the furnace in a number of ways. A saving of over 30 percent of the direct electrical energy requirements is realized in this furnace. The KES process is shown in Figure 7.

In general all iron and steel making processes are evolving with the increased use of oxygen as a basic part of this evolution.

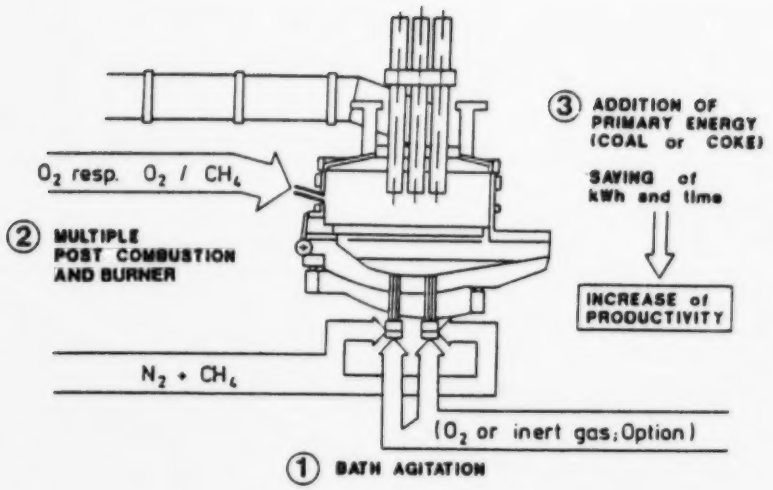
3 ADDITION OF PRIMARY ENERGY (COAL or COKE)
SAVING of kWh and time
INCREASE of PRODUCTIVITY
O_2 resp. O_2 / CH_4
2 MULTIPLE POST COMBUSTION AND BURNER
N_2 + CH_4
(O_2 or inert gas; Option)
1 BATH AGITATION

FIGURE 7 - THE KES PROCESS

4.3 The Use of Oxygen in Ontario's Non-Ferrous Smelters and the Potential for Increased Oxygen Usage

General

Inco limited, Falconbridge and Kidd Creek were contacted to determine their current usage of oxygen and their production capabilities. They were also asked what their future plans for expanding their oxygen consumption and production are. Contact was also made with the various oxygen producers to establish the current supply picture for oxygen and plans for increasing production.

Both, Inco and Kidd Creek utilize large quantities of oxygen in their smelting operations, whereas Falconbridge does not. Falconbrdige uses only minor quantities which are trucked to the smelter in bottles. A decision has been made to use purchased liquid oxygen in the converters by year end to increase Falconbridge Ltd capacity to treat secondary materials.

Inco and Kidd creek own and operate their own oxygen plants which are run at capacity.

INCO LIMITED

Inco produces oxygen at present at a rate of 1225 tonnes/day with a power demand of 21 MW.

Inco has placed an order for a cryogenic 556 tonnes/day oxygen plant with Canadian Liquid Air for delivery in 1991. This plant has high turn-up and turn-down ratio with a fast response time. This plant is expected to require 7.5 MW.

KIDD CREEK

Kidd Creek's current nominal oxygen capacity is 460 tonnes/day. It can fluctuate up or down depending on weather conditions. The capacity of the oxygen plant is fully utilized. The approximate energy demand is 9.8 MW.

Kidd plans to increase copper production. To be able to do this additional oxygen production capacity is required. Several options are being evaluated by Kidd Creek. The estimated increase in oxygen production capacity ranges from 100 to 200 tonnes/day. Both, cryogenic and vacuum swing absorption are being evaluated. Depending on the option selected, the demand requirement can range from 1.5 to 4.5 MW. The current plan is to have the new oxygen plant in place by 1991.

Falconbridge Limited

Falconbridge Ltd will be using oxygen in their converters to increase the convertor's capacity to treat secondary materials (Scrap). Liquid oxygen will be purchased at a projected rate of 25 tonnes per day. Installation of the storage facilities is scheduled to be completed by the end of 1990. The use of oxygen for boosting the roaster capacity is still under discussion, but no decision has been made to date.

5.0 LOAD SUBSTITUTION POTENTIAL

The steel industry is indirectly adding to the need for increased electrical energy input by employing increasing quantities of oxygen. This is particularly true in the integrated companies (BF/BOF). There is an increasing trend by the non integrated companies (EAF) to use ever greater quantities of oxygen and carbon sources to reduce the need for electrical energy for melting. The introduction of these fuels with oxygen uses the non-electrical energy source more efficiently. On average, one MWh used in the production of oxygen reduces the electrical energy required by electric arc furnaces for melting steel scrap by approximately 7 MWh. Considering the total steel produced in Ontario via the electric furnace this results in a large substitution potential of oxygen for direct electrical input to electric furnaces. As mentioned earlier companies will make use of this potential saving by making more steel which will be required in the future. However, this is a true power saving because it reduces the new power requirements which would have had to be produced to meet the 1%/annum expansion in the steel industry expected over the next 10 years. In the non-ferrous sector, however, there will be no substitution potential. All oxygen used is to either increase production capacity or overcome environmental problems.

6.0 LOAD SHIFTING POTENTIAL

Energy rate incentives have been put in place by Ontario Hydro to attempt to shift some of the peak energy demand load from the daytime to an off-peak night shift. This has led to performing a series of calculations (Appendix 2) to determine if oxygen production could be cut during the 16 hours of peak electrical demand. Excess oxygen could be produced and stored as liquid during the 8 hours of off-peak reduced power costs which could be used to meet the shortfalls during the peak hours resulting from reduced peak production. Some of the energy expended to liquify and store the oxygen off peak could be recovered by pre-cooling incoming air. The objective was to determine if a cost savings could be realized by supplying oxygen at a rate of 600 tonnes/day by operating on a load shifting schedule. In order to supply oxygen at 600 tonnes/day when operating under load shifting conditions, an oxygen plant having 750 tonnes/day is required as well as storage capacity for 50 tonnes of liquid oxygen (LOX). The added capital cost for this plant is $3.11 million or at a capital write off of 15%, $466,500/yr. The energy cost for the load shifting option is lower than that of straight operation of 600 tonnes/day by $248,000/yr. Therefore, the extra cost for introducing load shifting is approximately $218,500/yr. There is no economic incentive for a company to produce oxygen off-peak if one considers the extra capital cost versus the energy saving. The payback based solely on energy savings is in

the order of 13-14 years. If a larger plant turndown were considered during peak demand, such as 50 percent, a larger plant overcapacity would be required. A 900 tonne/day plant would be required to supply 600 tonnes/day. Although the energy cost savings more than double, the capital cost of the 900 ton/day required is also doubled. Thus, with the current Ontario Hydro incentives it does not appear economical to design a plant overcapacity in order to produce O_2 off-peak. The only way that off-peak incentives are attractive is for a plant with existing unused production capacity such as Union Carbide in St. Sault Marie and to some degree for Canadian Liquid Air in Hamilton. In these situations the only necessary capital requirement may be some additional storage capacity.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 The overall increase in power requirements for oxygen production for the metals industry is estimated to be 24 MW by the year 2000. This is offset by a 22 MW savings in direct electrical energy in the electric furnace as a result of the use of oxygen.

7.2 Electrical furnace steel producers will increase their use of oxygen from 18.5 Nm^3 to 34 Nm^3 per tonne of steel.

7.3 Increased oxygen usage in the electric arc furnace increases the direct use of hydrocarbon fuels and thus lowers the direct electrical energy need by about 62 kWhr/tonne of steel or 22 MW in total for the industry.

7.4 The decreased power requirements of the electrical furnace 22 MW is therefore partly offset by the power required to produce the oxygen 3 MW. The net saving will be 19 MW.

7.5 The arc furnace steel producers will likely take advantage of the increased productivity resulting from oxygen usage and therefore will continue to use power to the limits of their transformers. The net result will be a reduction of power requirements for future increases in production.

7.6 The integrated steel producers will further increase the use of oxygen in a major way by enriching the air blast in the blast furnace to support high levels of coal injection and for the improvement of scrap melting capability of the oxygen steel making vessels. One Canadian integrated plant has planned to partially replace their coke ovens with oxygen/coal injection. If the rest of the Ontario industry adopted this injection technology then an additional 1280 tonne/day of oxygen will be required resulting in 23.5 MW of load.

7.7 The oxygen consumption in the non-ferrous industry will increase by at least 556 tonnes/day in the near future corresponding to a power draw of 7.5 MW. An additional power requirement of 1.5-4.5 MW is likely, depending on the decision reached by Kidd Creek.

7.8 It is believed that future sulphide smelting processes will be based on oxygen smelting. Therefore, if any new smelters are based in Ontario, oxygen production requirements will increase.

7.9 The application of load shifting to the operation of oxygen plants does not appear to be economically viable, unless an existing plant has excess capacity.

7.10 It is recommended that Ontario Hydro's pilot electric furnace be set up as a test bed to demonstrate the most efficient methods of introducing carbon and oxygen into the electric furnace so that direct electrical energy requirements may be reduced by as much as 30% in the foreseeable future.

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APPENDIX I

SUMMARY OF OPERATING AND PROPOSED OXYGEN PLANTS IN ONTARIO

PLANT NO.	1	2	3
OWNER, COMPANY	INCO	INCO	INCO
LOCATION	SUDBURY	SUDBURY	SUDBURY
STATUS	OPERATING	OPERATING	PLANNED
PROCESS	Cryo	Cryo	Cryo
ASSOCIATED WITH INDUSTRY	Non Ferrous	NF	NF
Supplier of Plant	CLA	CLA	CLA
Rated Capacity, tonnes/day		1225	556
Actual Capacity, tonnes/day		1225	
Summer			
Winter			
Product Grade, 02, %	96.0	96.0	96.0
Product Form	Gas	Gas	Gas
Delivery Pressure, psig	30	30	30
Specific Energy, kWh/tonne		419	319
Connected Power, MW		21	7.5
STORAGE CAPACITY		200	
Oxygen, tonnes		Liquid	
Form			
Nitrogen, tonnes			
Form			
By-Products			

COMMENTS: Start up planned April 1991, Plant designed for a high turn-up and turndown ratio

PLANT NO.	4	5	5
OWNER, COMPANY	Kidd Creek	Kidd Creek	Kidd Creek
LOCATION	Timmins	Timmins	Timmins
STATUS	OPERATING	OPERATING	PLANNED
PROCESS	Cryo	Cryo	Cryo or VSA
ASSOCIATED WITH INDUSTRY	Non Ferrous	NF	NF
Supplier of Plant	Air Prod.	A P	Open
Rated Capacity, tonnes/day	190	240	100-200
Actual Capacity, tonnes/day			
Summer	230	250	
Winter	210	245	
Product Grade, 02, %	95	95	93-95
Product Form	Gas	Gas	Gas
Delivery Pressure, psig	45	45	4-45
Specific Energy, kWh/tonne	450-500	450-500	450
Connected Power, MW	4.5	5.3	1.5-4.5
STORAGE CAPACITY		140, live	
Oxygen, tonnes		Liquid, 4 tanks.	
Form			
Nitrogen, tonnes			
Form			
By-Products			
COMMENTS: Energy Consumption will depend on process selected.			

PLANT NO.	7	8	9
OWNER, COMPANY	Canadian Liquid Air	Canadian Liquid Air	Canadian Liquid Air
LOCATION	Hamilton	Hamilton	Hamilton
STATUS	OPERATING	OPERATING	Stand-By
PROCESS	Cryo	Cryo	Cryo
ASSOCIATED WITH INDUSTRY	Steel	Steel	Steel
Supplier of Plant	CLA	CLA	CLA
Rated Capacity, tonnes/day	1090	635	544
Actual Capacity, tonnes/day	1225	635	-
Summer			
Winter			
Product Grade, 02, %	99.5	99.5	99.5
Product Form	Gas + 20% Liquid		Gas
Delivery Pressure, psig	600	600	600
Specific Energy, kWh/tonne			
Connected Power, MW		50 to 60	
STORAGE CAPACITY		6500 in two tanks Liquid	
Oxygen, tonnes			
Form		2400 in two tanks	
Nitrogen, tonnes			
Form			
By-Products	Ar, Ne, Kr		
COMMENTS:	Specific Energy High because product at high pressure and partially as a liquid		Plants 9 & 10 only used when units 7 & 8 are down.

PLANT NO.	10	11	12
OWNER, COMPANY	Canadian Liquid Air	Canadian Liquid Air	Dofasco
LOCATION	Hamilton	Hamilton	Hamilton
STATUS	Stand-By	Potential	Operating
PROCESS	Cryo	Cryo	Cryo
ASSOCIATED WITH INDUSTRY	Steel	Steel	Steel
Supplier of Plant	CLA	CLA	CLA
Rated Capacity, tonnes/day	181	800	363
Actual Capacity, tonnes/day	-	-	-
Summer			
Winter			
Product Grade, 02, %	99.5	99.5	99.5
Product Form	Gas	Gas	Gas
Delivery Pressure, psig	600	?	?
Specific Energy, kWh/tonne		est. 450	Est. 450
Connected Power, MW		13.6	6.8
STORAGE CAPACITY			
Oxygen, tonnes			
Form			
Nitrogen, tonnes			
Form			
By-Products			
COMMENTS:	Plants 9 & 10 only used when units 7 & 8 are down.	Planned for 1994/95 if Stelco will use 02 in Blast Furnaces	

PLANT NO.	13	14	15
OWNER, COMPANY	Dofasco	Dofasco	Union Carbide
LOCATION	Hamilton	Hamilton	St. Sault Marie
STATUS	Stand-By	Scrapped	Operating
PROCESS	Cryo	Cryo	Cryo
ASSOCIATED WITH INDUSTRY	Steel	Steel	Steel
Supplier of Plant	CLA	CLA	UC.
Rated Capacity, tonnes/day	150	100	544
Actual Capacity, tonnes/day	-	-	-
Summer			
Winter			
Product Grade, 02, %	99.5	99.5	99.5
Product Form	Gas	Gas	Gas
Delivery Pressure, psig	?	?	600
Specific Energy, kWh/tonne			Est. 450
Connected Power, MW			24.0
STORAGE CAPACITY			
Oxygen, tonnes			1000
Form			Liquid
Nitrogen, tonnes			48
Form			Liquid
By-Products			
COMMENTS:	Will be operated only if Plant #12 is down		

PLANT NO.	16	17	18	19
OWNER, COMPANY	Union Carbide	Air Products	Union Carbide	Liquid Carbonic
LOCATION	St. Sault Marie	Nanticoke	Oakville	Scarborough
STATUS	Operating	Operating	Operating	Operating
PROCESS	Cryo	Cryo	Cryo	Cryo
ASSOCIATED WITH INDUSTRY	Steel	Steel	Merchant	Merchant
Supplier of Plant	US.	AP & Chem.	UC.	UC
Rated Capacity, tonnes/day	544	590	163	150
Actual Capacity, tonnes/day	-	-	-	-
Summer				
Winter				
Product Grade, 02, %	99.5	99.5	99.5	99.5
Product Form	Gas	Gas	Liquid only	Liquid only
Delivery Pressure, psig	600	est. 600		
Specific Energy, kWh/tonne	est. 450			
Connected Power, MW		est. 12.0	11.0	9.0
STORAGE CAPACITY				
Oxygen, tonnes			1000	?
Form			Liquid	
Nitrogen, tonnes			1630	?
Form			Liquid	
By-Products			N2 522 tonnes/day	N2 250 tonnes/day Ar 8 tonnes/day
COMMENTS:		Air Products provided only minimum information.		

APPENDIX 2

APPENDIX 2

Data Used in the Calculation

The following data were used in the calculations.

Oxygen Requirement: 600 tonnes/day at a steady rate.

	hrs/day	c/KWh
Peak Power Operation	16	4.5
Off Peak Power Operation	8	2.5

Energy Requirements for Oxygen Production

Source: Canadian Liquid Air

	KWh/tonne
Gas @ 30 psig	300
Lox	800

Capital Cost (Source: Canadian Liquid Air)

Oxygen Plant Cost (30 psig delivery pressure)

Capacity, Tonnes/day	$ Million
600	26.0
750	29.0
900	32.0

Lox Storage Cost

For	50 tonnes	$110,000
For	100 tonnes	180,000

CALCULATIONS: For Load Shifting Feasibility

1. Calculation Of Plant Size

Total O_2 requirement on a steady basis 600 tonnes/day.

Plant capacity required to meet load shifting requirement for a 30% turndown during peak operation.

X (0.7 x 25 x 16 + 1.0 x 25 x 8) = 600

$$X = \frac{600}{(280 + 200)} = 1.25 \textit{ oversize factor}$$

Plant Capacity Required = 1.25 x 600 = 750 tonnes/day

2. Liquid Oxygen (LOX) Storage Capacity Required

Oxygen Demand 25 tph
Plant Delivery: Peak 750 x 0.7/24 = 21.875 tonnes/hr
Off-Peak 750/24 = 31.25 tonnes/hr

∴ Lox Storage Capacity Required = (31.25-25.0)X8 = 50.0 tonnes

3. Energy Cost Calculation

3.1 No Load Shifting

Energy Lost During Peak 16 hr = 0.045 $/kWh
Energy Lost During Off-Peak 8 hr = 0.025 $/kWh

	$/Day
Peak 400 x 300 x 0.045	5,400.00
Off peak 200 x 300 x 0.025	1,500.00
	$6,900.00/day
	= $2.484 x 10^6/yr

3.2 With Load Shifting

Peak	2.875 x 16 x 0.045 x 300 =	4725.00
Off-Peak(Gas)	200 x 0.025 x 300 =	1500.00
Off-Peak(Lox)	50 x 0.025 x 800 =	1000.00
		7225.00

Daytime Recovery of Energy From =	(50 x 0.045 x 450)
Stored Lox (Assume 90% Recovery) =	1013
Total Energy Cost	$6212/day
	= $2.236 x 10^6/yr

Energy Cost Savings From Load Shifting = $248,000/yr

4.0 EQUIPMENT COST

4.1 Cost of Storing Lox, Tank
Capacity for 50 tonnes = $110,000

4.2 Capital Cost for Oxygen Plant
(delivery at 30 psi)

Plant Capacity 750 tonnes/day	$29.0 million
Plant Capacity 600 tonnes/day	$26.0 million
Difference	$ 3.0 million

4.3 Total Additional Capital Cost Resulting From Load Shifting

Oxygen Storage Cost	0.110 million
Oxygen Plant Additional Cost	3.000 million
Total	3.100 million

Assume Capital Write off at 15%/year
Cost is $/Year - $466,500

4.4 Annual Cost Resulting From Load Shifting

		$/Year
	Capital (15%/yr)	$466,500
less	Energy Savings	248,000
	Total Cost	218,500

The payback on additional capital is in the order of 13-14 years if based solely on energy cost savings.

1) Total O_2 requirement on a steady basis 600 tonnes/day

Plant Capacity required to melt load shifting requirements based on 50% turndown during peak operation.

$$x(0.5 \times 25 \times 16 + 1.0 \times 25 \times 8) = 600$$

$$x = \frac{600}{400} = 1.50$$

Plant Capacity Required = 1.5 x 600 = 900 tonnes/day

2) Lox Storage Capacity Required

Oxygen Demand 25+ph
Plant Delivery: Peak 900 x 0.5/24 = 18.75
Plant Delivery: Off Peak 900/24 = 37.50

∴ Lox Storage Capacity Required = (37.5 - 25) x 8 = 100 tonnes

3.0 Energy Cost Calculation

3.1 No Load Shifting

Energy cost during peak - 16hr = 0.045¢/KWh
Energy cost during off-peak - 8 hr = 0.025¢/KWh

	$/day
Peak 400 tonne x 300 KWh/tonne x 0.045¢/KWh =	5400
Off-Peak 200 tonne x 300 KWH/tonne x 0.025¢/KWh =	1500
	$6900/day

$2.48 x 10^6/yr

3.2 With Load Shifting

Peak	18.75 x 16 x 0.045 x 300 =	4050
Off-Peak (Gas)	200 x 0.025 x 300 =	1500
Off-Peak (Lox)	100 x 0.025 x 800 =	2000
		7550

Daytime Recovery of Energy From	=	(100 x 0.045 x 450)
Stored Lox (Assuming 90% Recovery)	-	2025
		$5525/day
		$1.99 x 10^6/yr

Energy Cost Savings From Load Shifting $491,000

4.0 Equipment Cost

4.1 Cost of 100 tonnes storage tank = $180,000

4.2 Capital cost of oxygen plant (30 psi)

Plant Capacity 900 tonnes/day =	$32.0 million
Plant Capacity 600 tonnes/day =	$26.0 million
	$ 6.0 million

4.3 Total Additional Capital Cost Resulting From Load Shifting

Oxygen Storage Costs	0.180 million
Oxygen Plant Additional Cost	6.00 million
TOTAL	6.18 million

Assume Capital Write Off at 15%/yr

Annual Cost is $927,000/yr

4.4 Annual Cost Resulting From Load Shifting

	$/yr
Capital	927,000
Energy Saving	491,000
Total Cost	$436,000